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Experimental Study of EMP Upset Mechanisms in Analog and Digital Circuits

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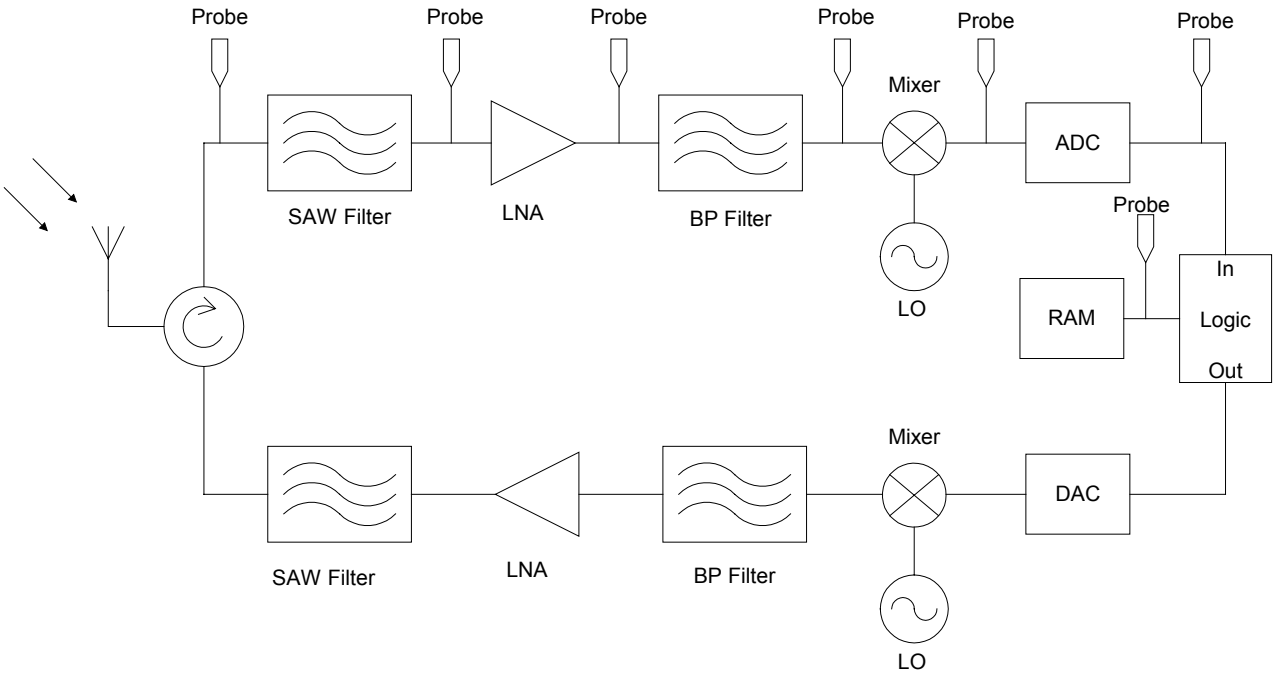
Outline and Motivation

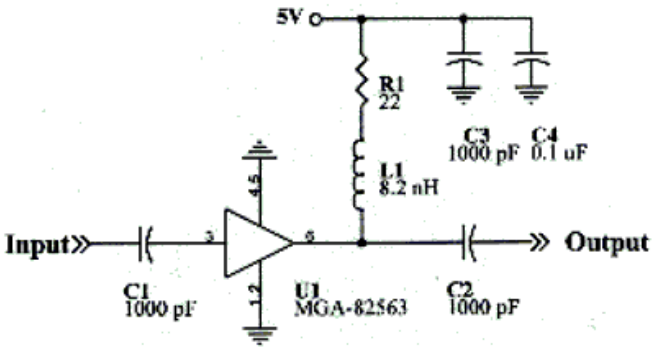
- *Out-of-band frequency response in communications circuits*
  - *Effect of parasitic elements on network performance*
  - *Degradation in filter rejection ratios*
  - *EMP propagation on signal path*
  - *Need for wideband circuit characterization and verification throughout the communications network (RF and IF path, mixer, A/D, power vias, etc.)*
- *Experimental study of device upset using direct RF injection*
  - *Identify RF characteristics that produce bit errors, latch-up*
  - *What are the EMP effects at the device level?*
  - *Modulation and nonlinear circuit response*
- *Directions to pursue*
  - *Experiment*
  - *Modeling*

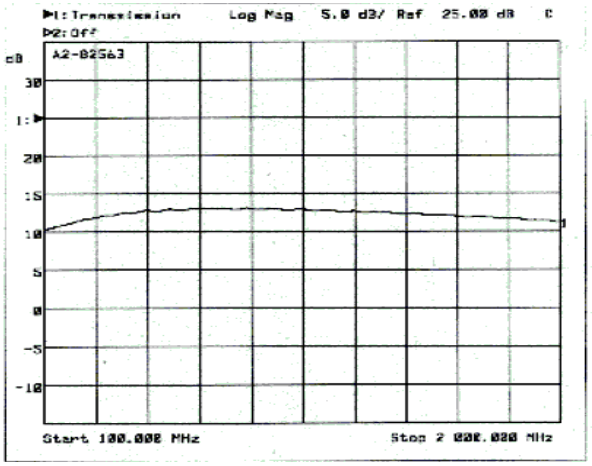
Schematic of a "loop-back" test circuit for investigating RF effects in digital communications systems and components

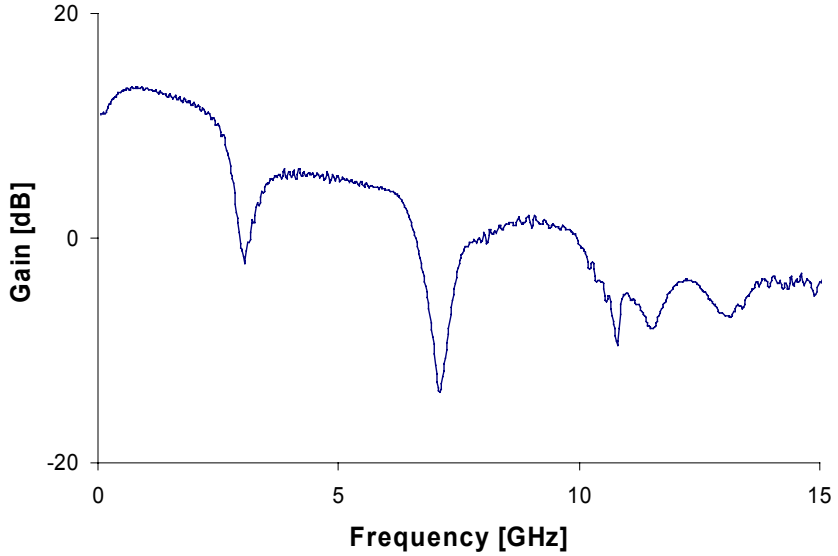


Find possible RF entry points, pathways and circuit effects that may upset the system or corrupt data.

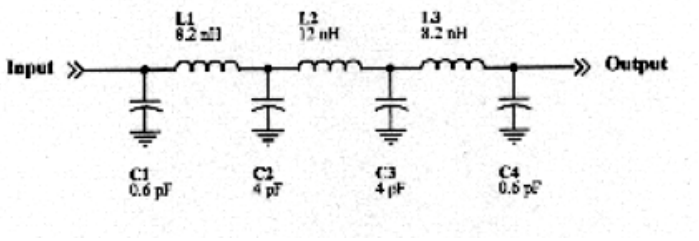
Example: 2 GHz RF LNA

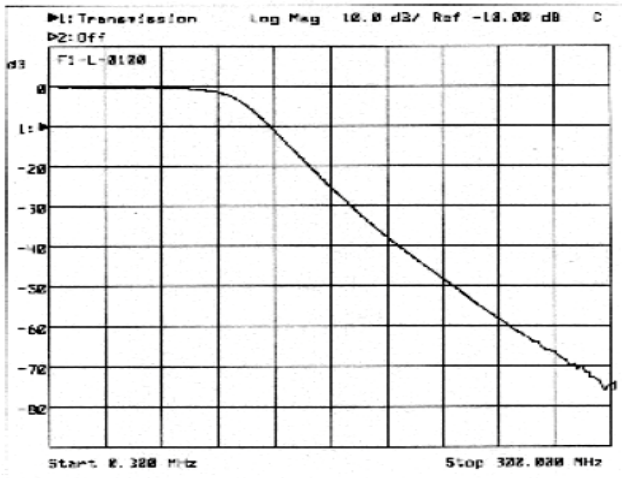


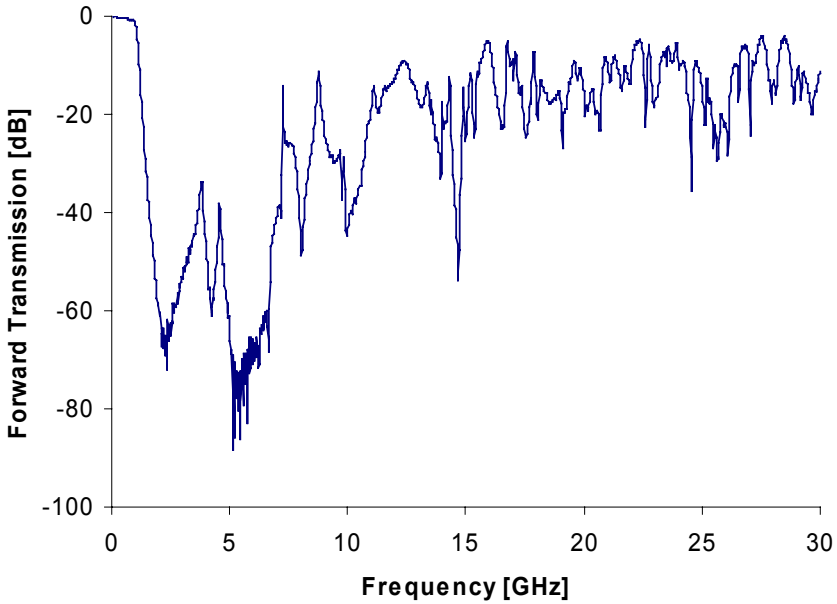




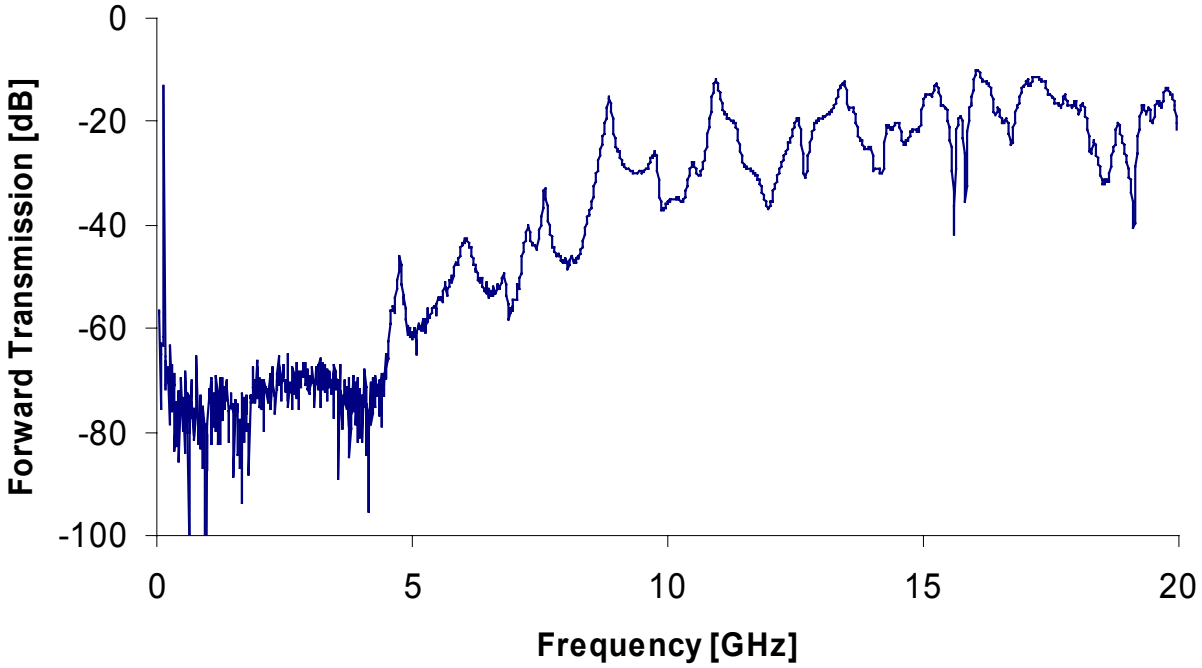
Example: 1 GHz low pass filter



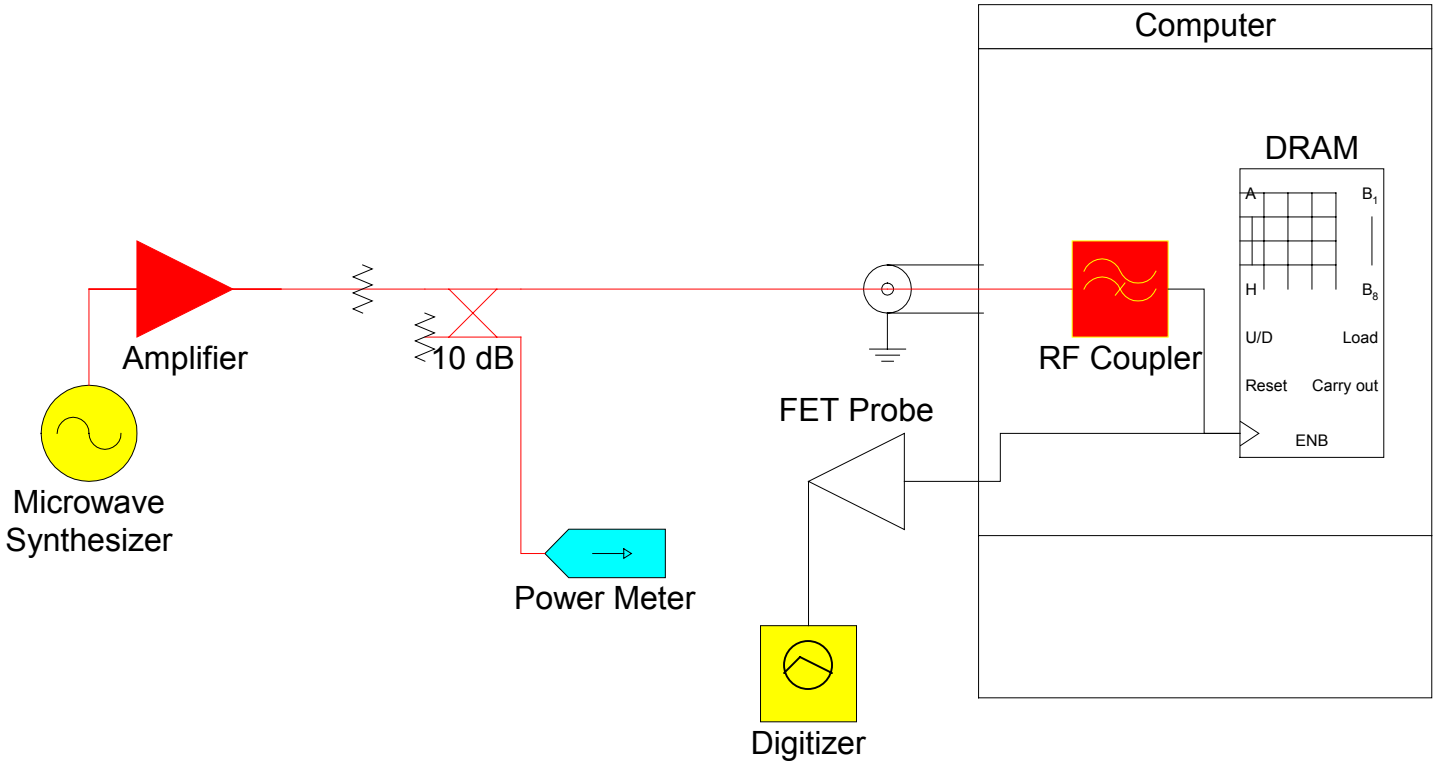




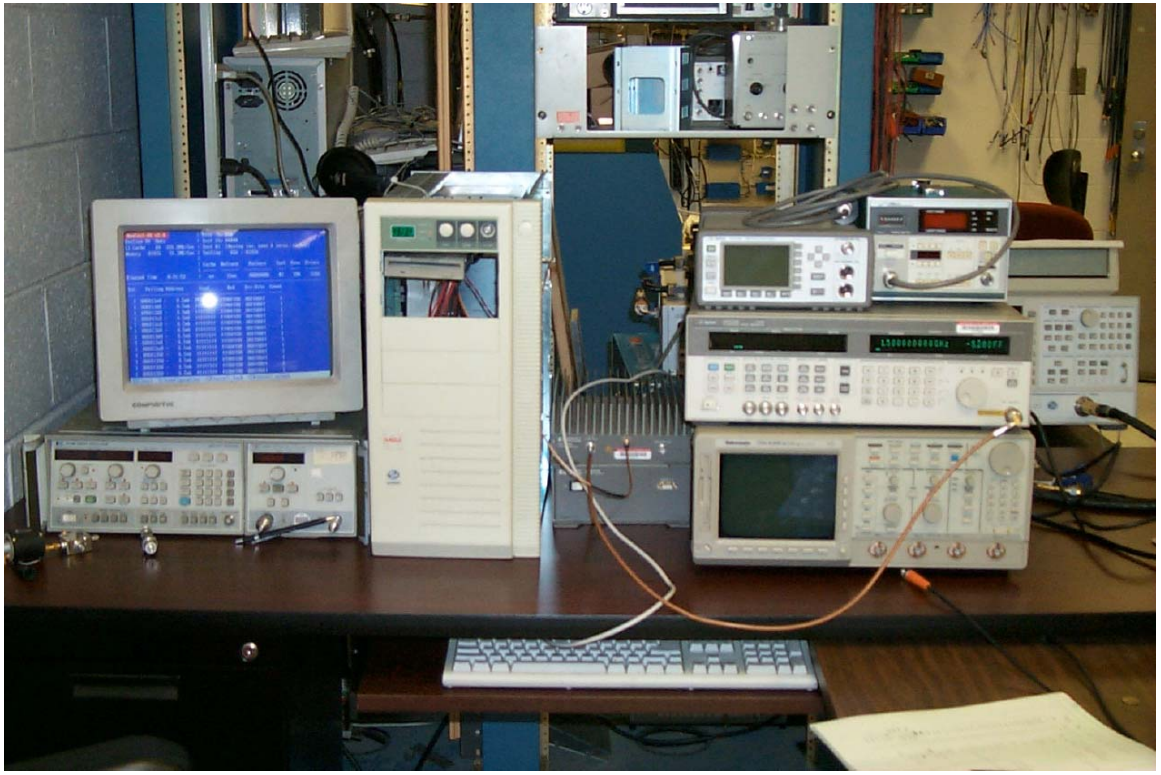
140 MHz IF surface acoustic wave (SAW) filter



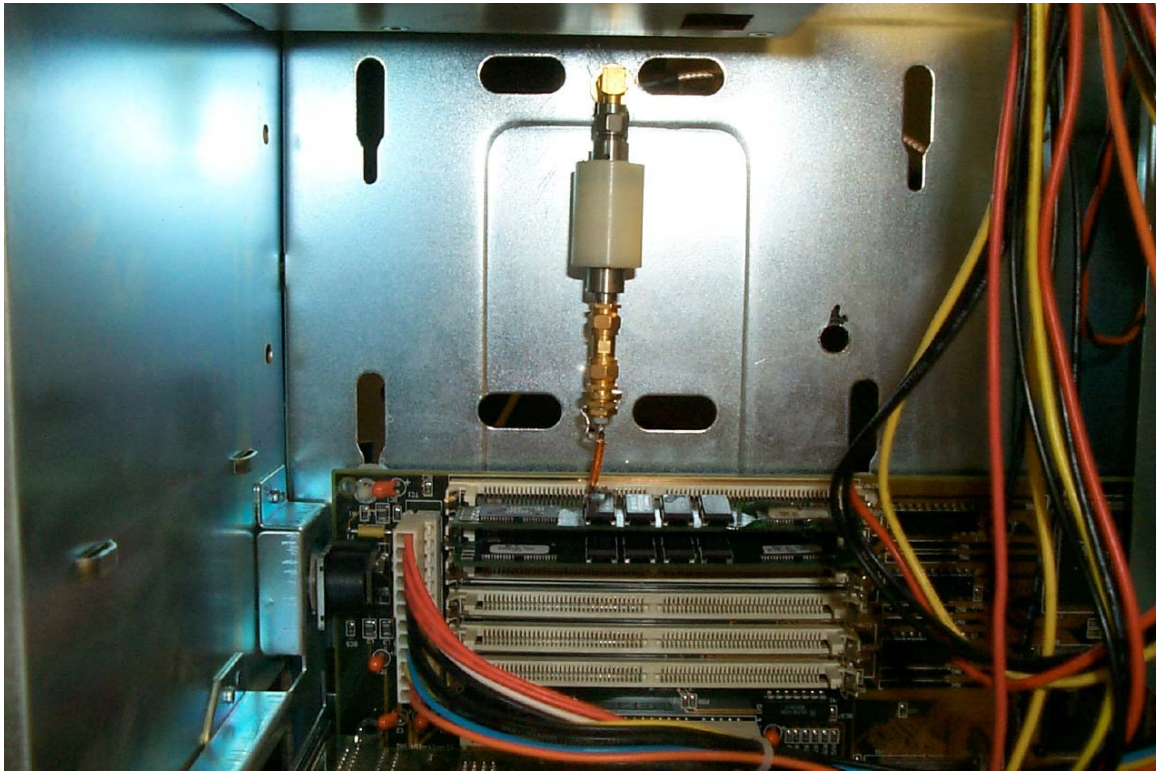
Schematic of direct injection experiment



Direct injection test facility

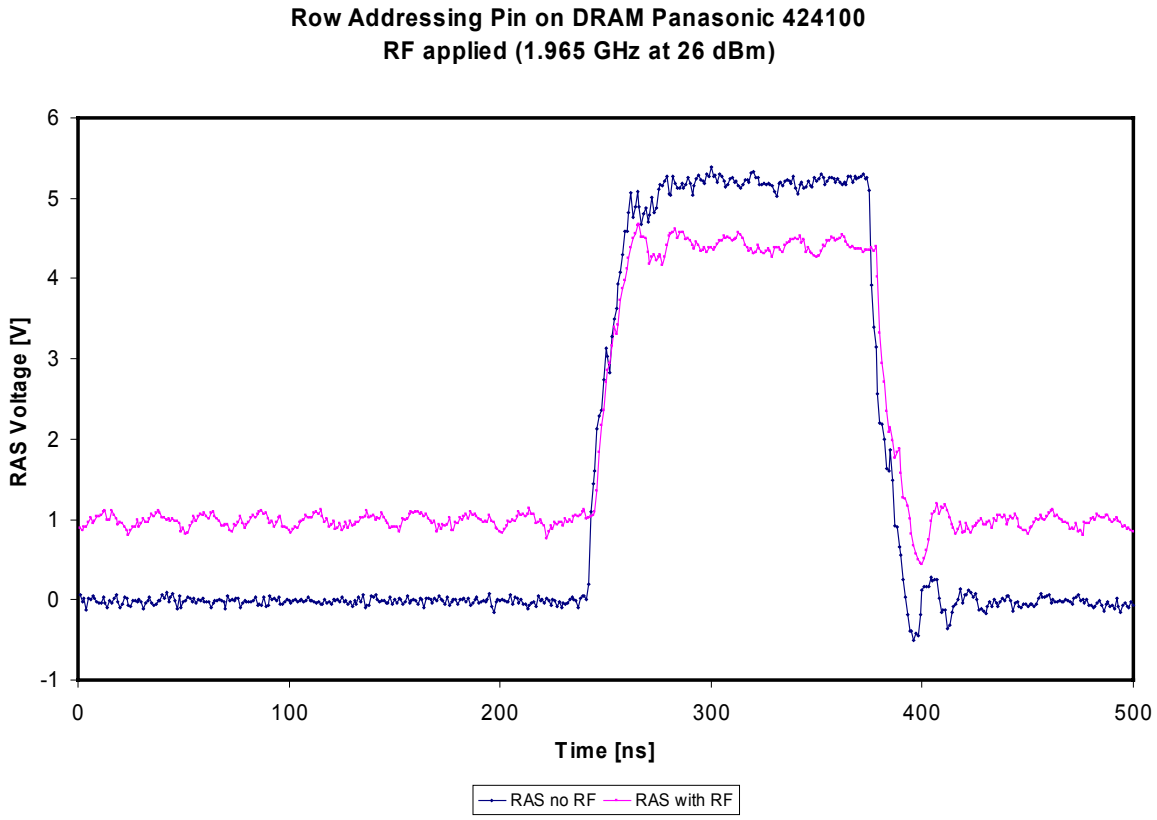


View of injection coupler and memory modules inside computer



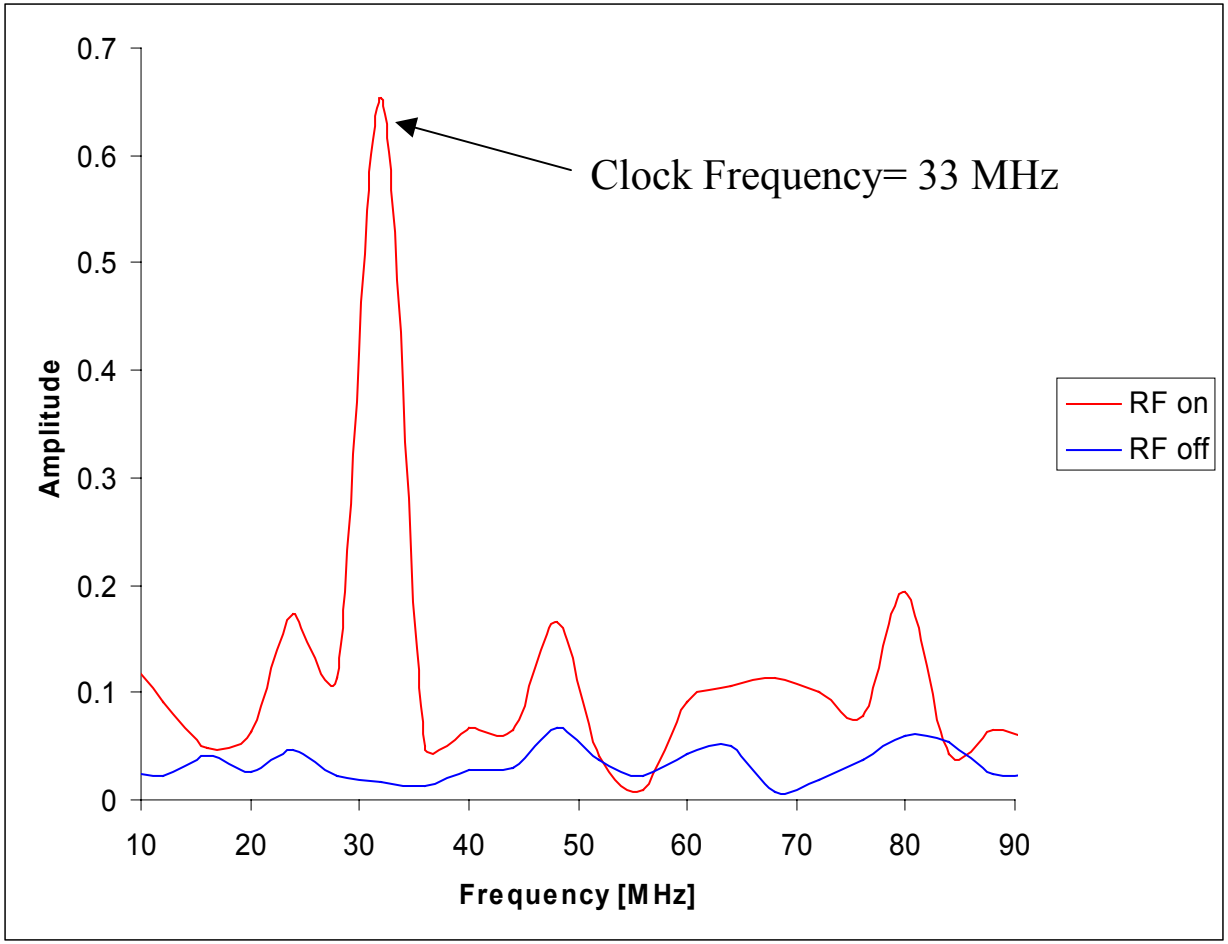
Memory checking code displaying bit errors

RAS logic waveform with and without RF injection

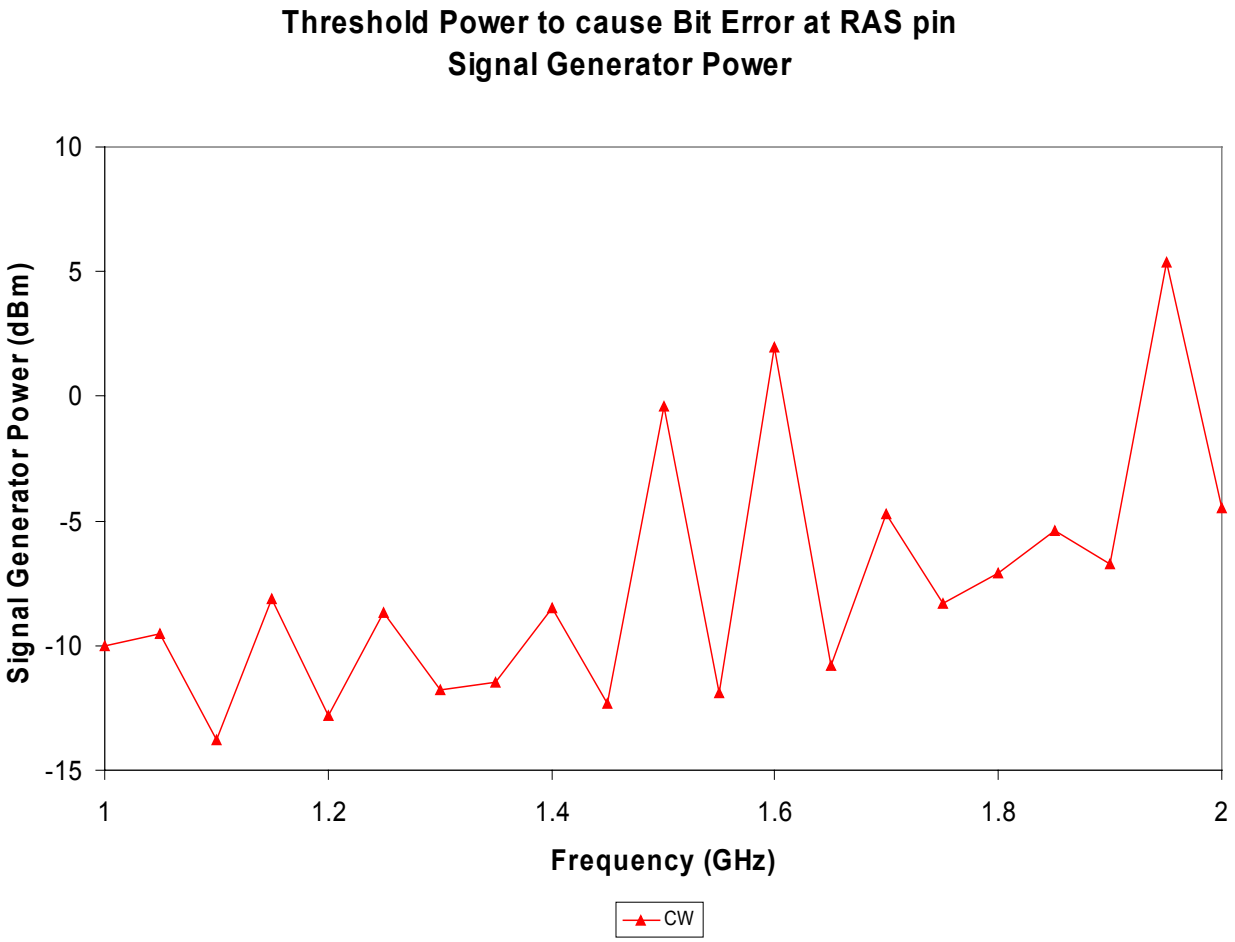


- Device no longer latches to Vdd and Vss
- RF changes operating bias point
- Susceptibility may involve synergistic effects where RF increases likelihood of interference from internal signals.

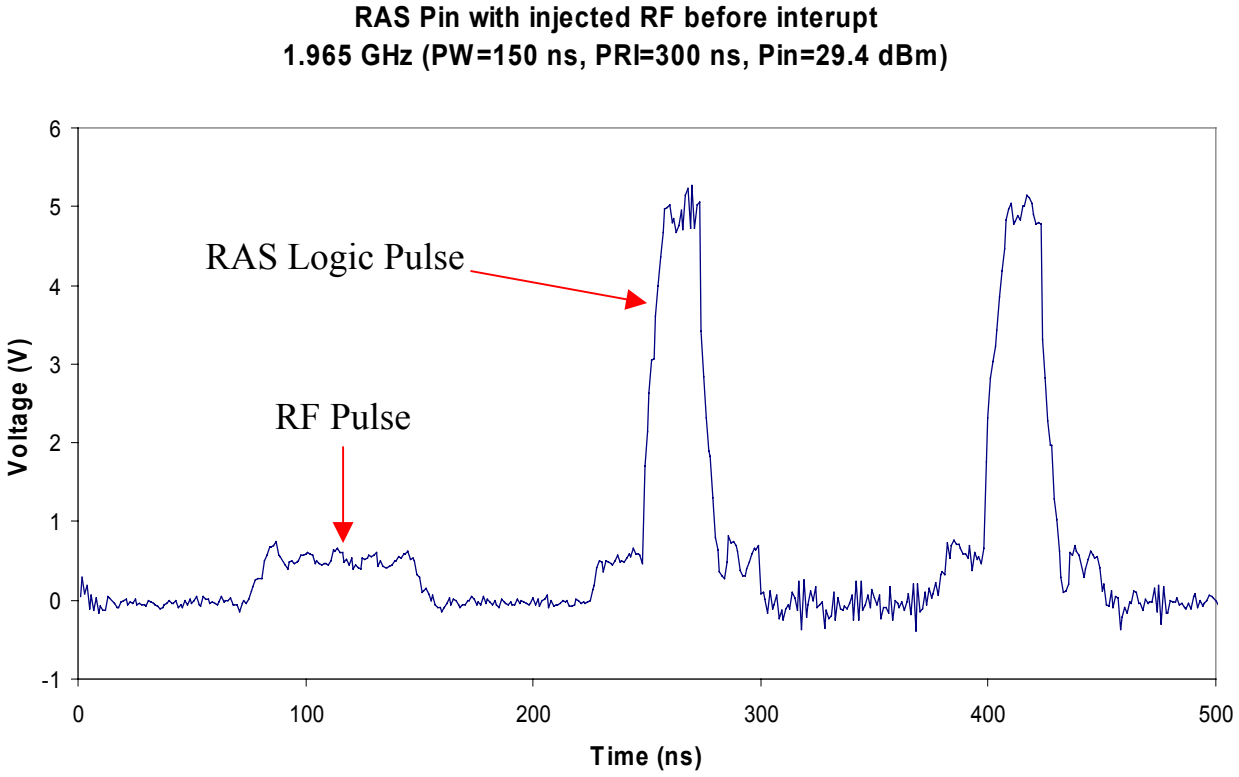
Frequency spectrum of RAS waveform



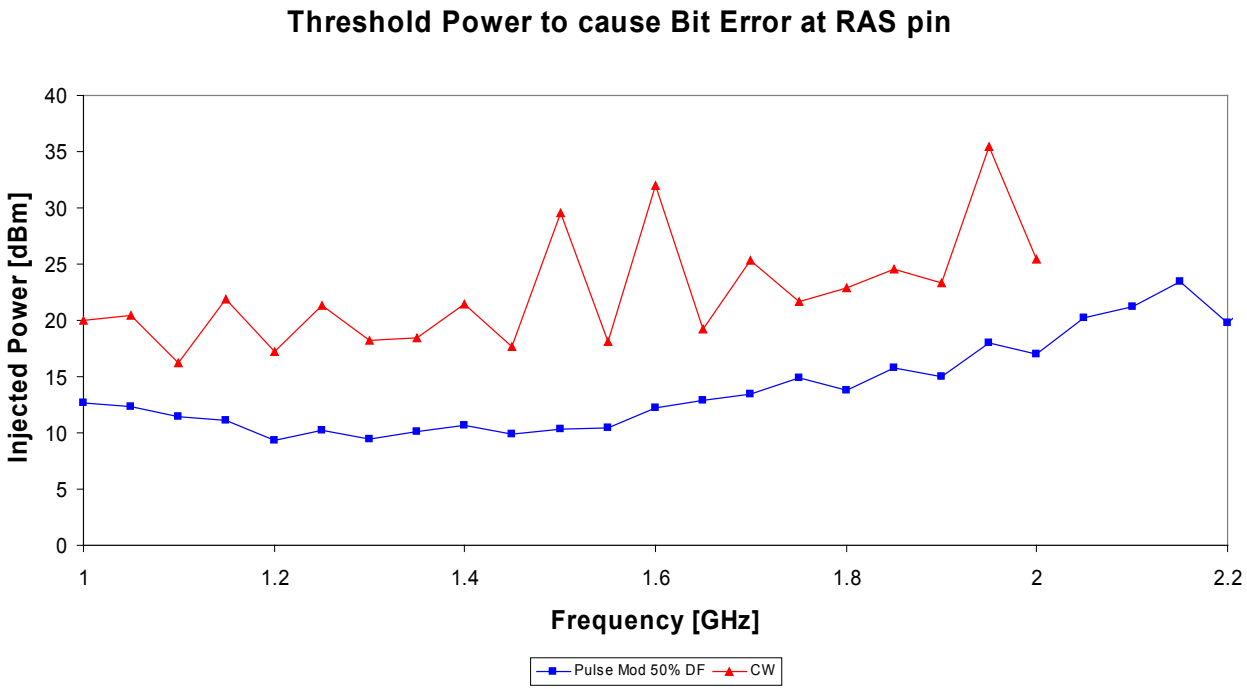
Results with CW injection



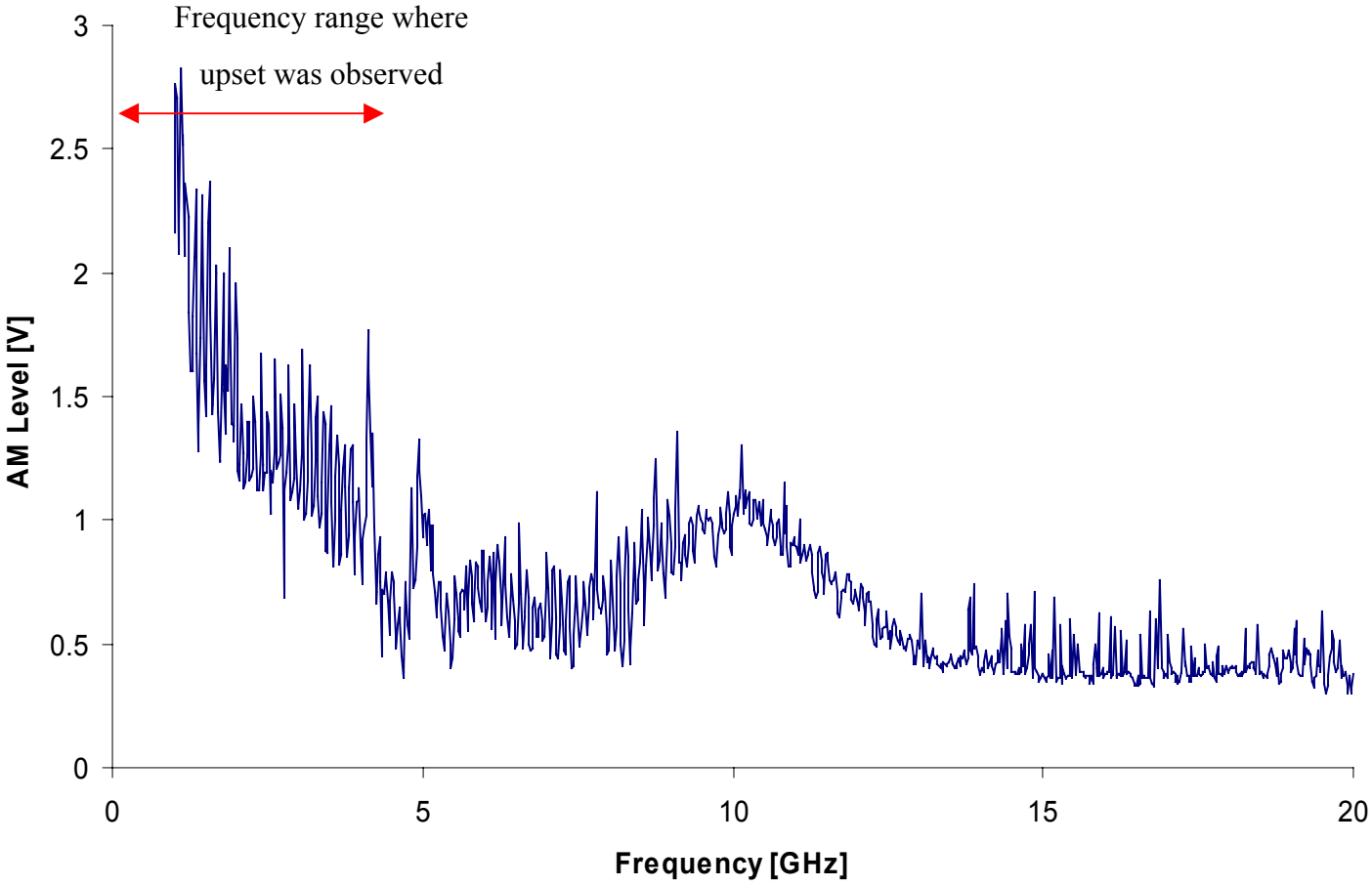
RAS Voltage vs. time with Pulsed RF Injection (f~2 GHz)



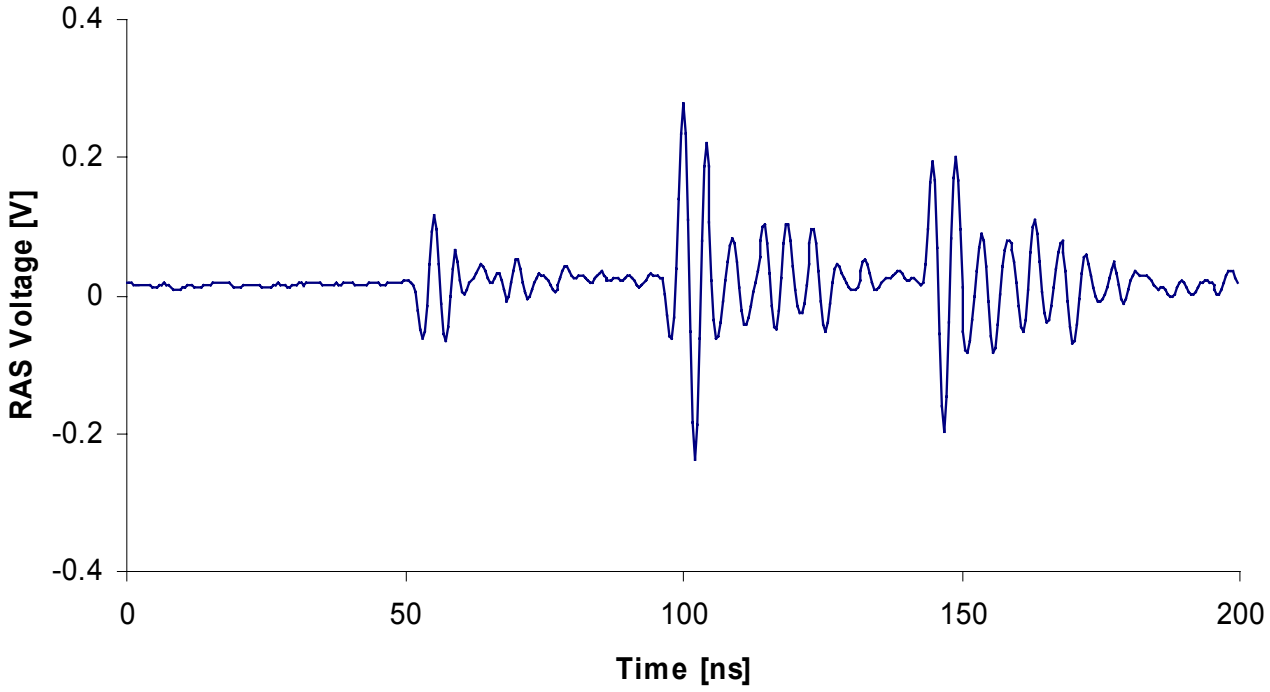
Comparison of results with CW and pulsed injection



Amplitude of demodulated RF signal on RAS vs. frequency



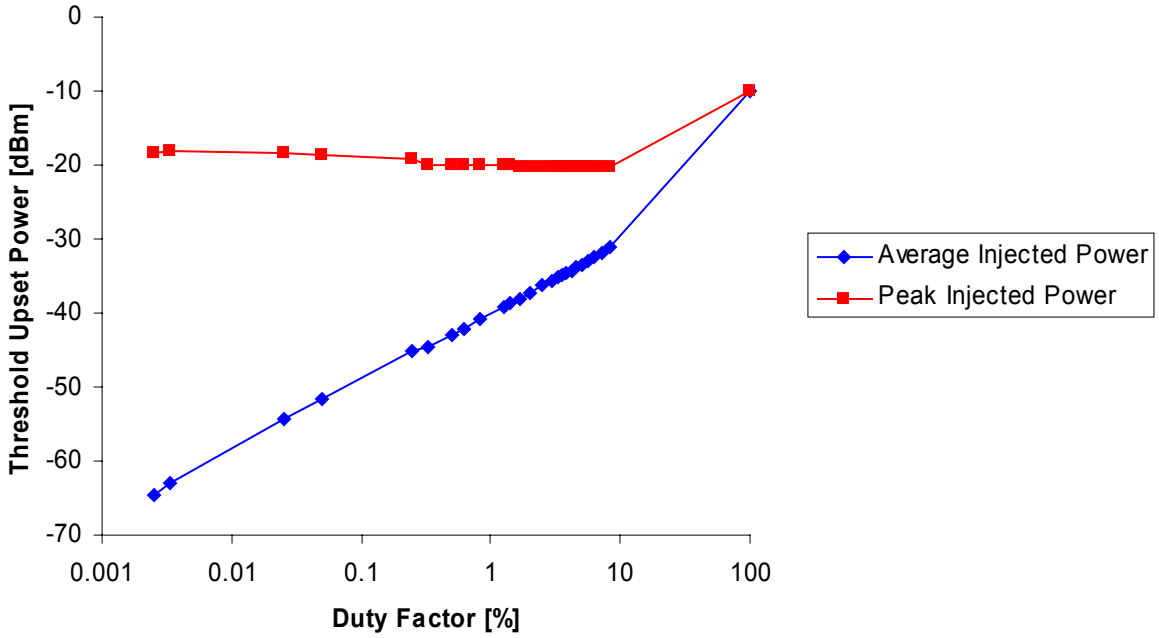
Transients induced on RAS by RF pulses at frequencies up to 20 GHz



What mechanisms may be responsible for the observed effects?

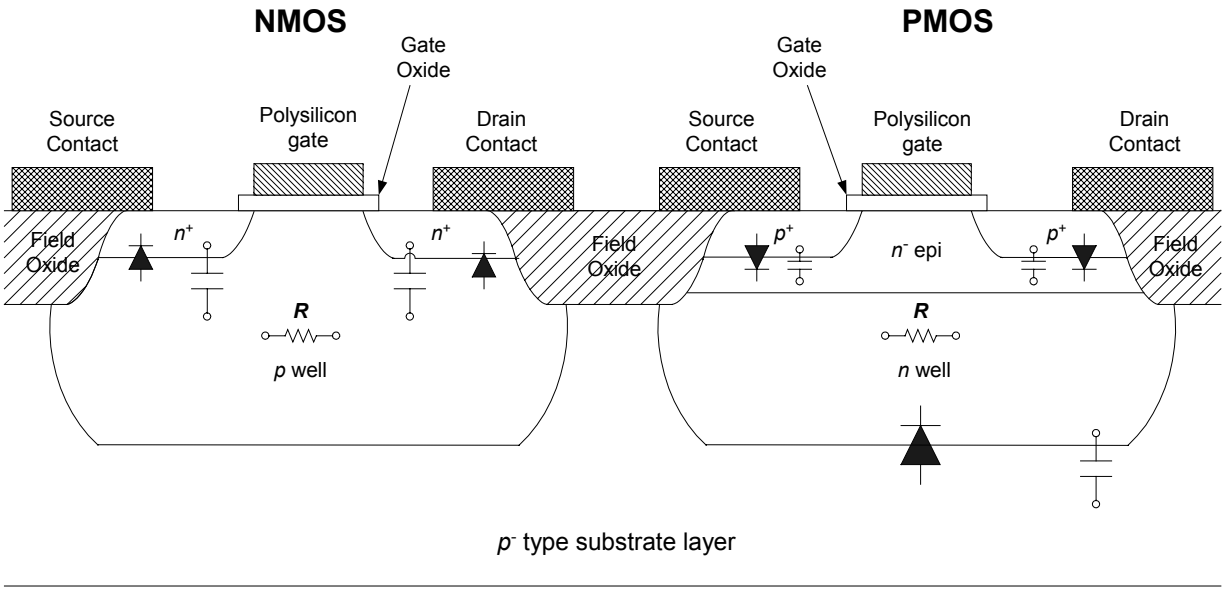
- Thermal: localized RF energy deposition and rapid heating of active MOS regions
- Hot-carriers
- Nonlinear circuit elements
  - MOS diodes acting as RF detectors
  - Demodulation of RF by parametric capacitances

Upset threshold power vs. duty factor

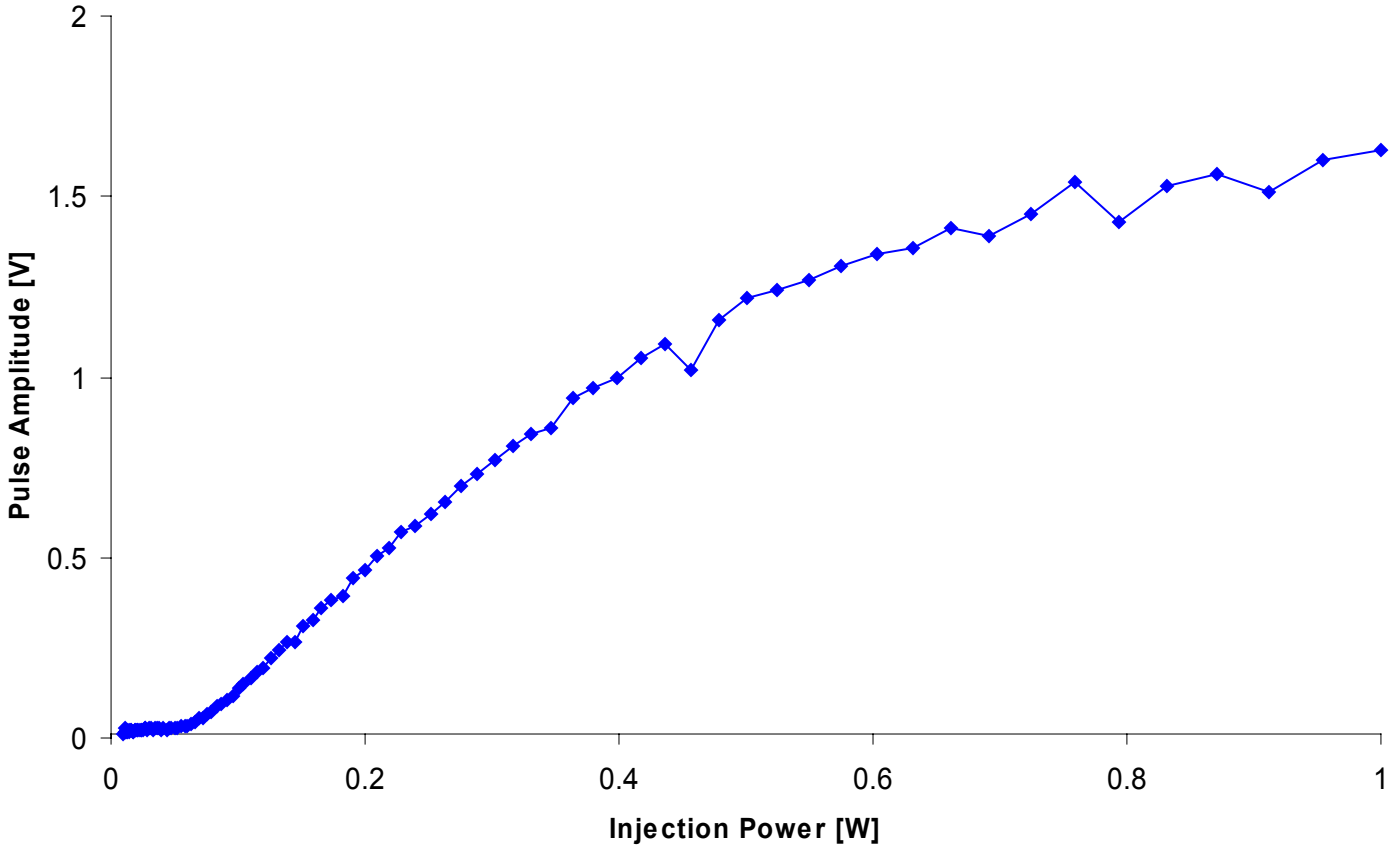


Not a thermal effect

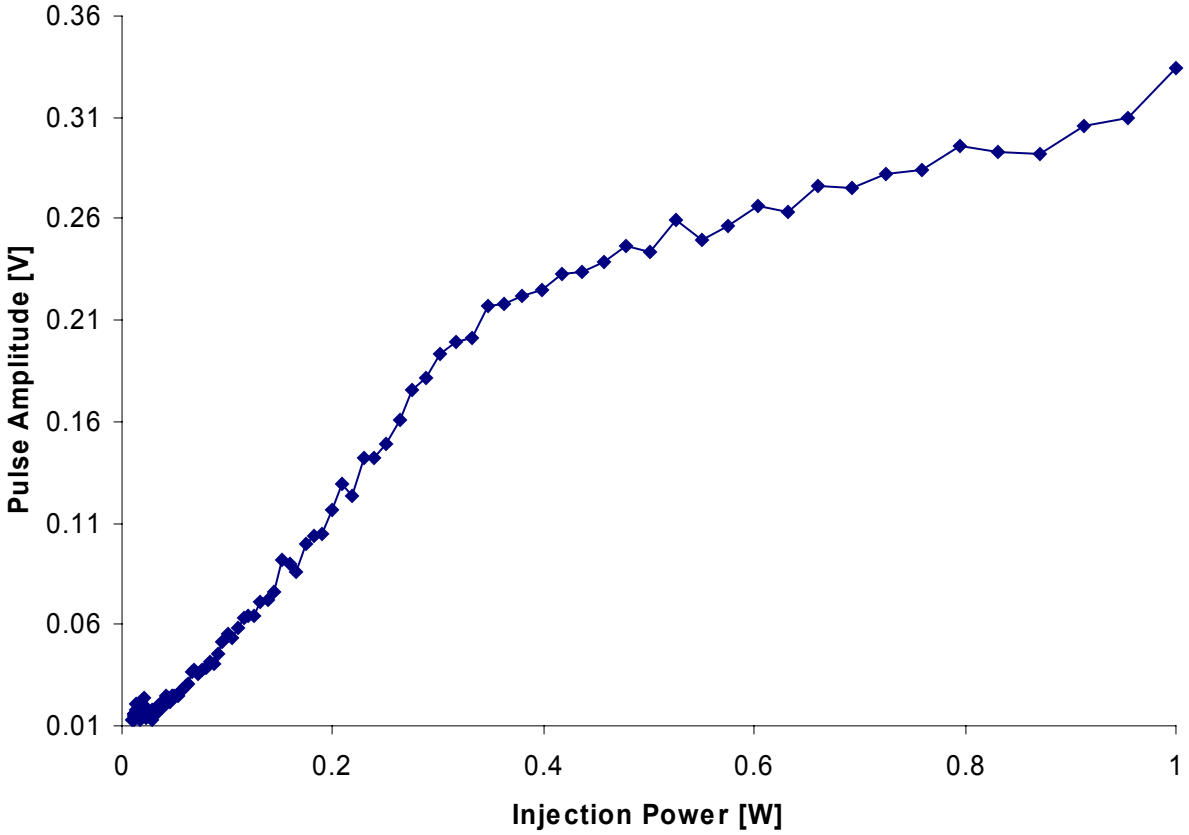
Physical Cross-section of CMOS showing equivalent circuit elements with nonlinear electrical characteristics



Drive characteristic of demodulated 4.12 GHz pulse



Drive characteristic of 6.0 GHz transient pulse



Conclusions

- High frequency response of communications circuits must be considered when analyzing susceptibility to determine probable entry and propagation paths for EMP.
- The RF shifts the operating bias with respect to Vdd and Vss into a nonlinear amplification regime, which could lead to instability, oscillation and chaotic behavior.
- RF pulses are demodulated by nonlinear MOS elements. The envelop voltage constitutes the interrupting signal.
- EMP rise time is a key parameter for inducing interrupt signals over wide bandwidths.

Future Work

- The experimental results give basis for modeling high frequency effects in devices
- Continue to characterize device-level upset mechanisms and seek to develop generalized formalisms
- Study the effects of complex modulation
- Look at smaller, faster structures (CPU, RDRAM, DDR, etc.) and investigate how scaling laws may be applied
- Investigated RF effects in mixed signal systems (A/D, demodulators, etc.)